

# Analysis of UARS MLS Radiance Variances and Their Relationship with Stratospheric Wind

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## 1. Introduction

Our ability to understand any component of the atmospheric motion is often tested by our ability to observe its throughout characteristics in various facets. It is now well known that an accurate simulation of the middle atmosphere and the prediction of its response to the anthropogenic forcing requires a credible treatment of the stratospheric dynamics, in which atmospheric gravity waves play a crucial role. That emphasizes our needs for better observation techniques to provide information on gravity wave generation, propagation, distribution, variation, breaking and saturation. Gravity waves usually induce air temperature fluctuations that can be detected by satellite sensors. Recently, the 63GHz microwave radiance variance data obtained from the Upper Atmospheric Research Satellite (UARS) Microwave Limb Sounder (MLS) has shown important spatial and seasonal patterns that may link to strong gravity wave activities at mid- to high latitudes of winter hemispheres and at sub-tropical regions of summer hemispheres [1,2]. It has been found that MLS data depends strongly on viewing geometries associated with various instrument operation modes, such as up/down-ward scanning modes, limb tracking mode, as well as whether the MLS is on ascending or descending orbits and in north or south-looking views [2,3]. This viewing angle dependence is caused by the spatial distribution and orientation of the MLS temperature weighting function [2,4]. Because of the spatial asymmetry of the weighting function, the MLS radiance response to atmospheric temperature perturbations depends strongly on wave propagating direction. The observed radiance variance is larger when the instrument line-of-sight (LOS) direction is aligned with wave-phase lines. A more detailed simulation for the MLS limb-scan and limb-track variance response is shown in Wu and Jiang [4].

The MLS saturated radiances measure the atmospheric temperature at altitudes well above the wave source regions. When the gravity wave energy propagates upward into the stratosphere, the local airflow perceives it at a Doppler-shifted frequency, lower if the wave phase travels in the same direction and higher if the two velocities are opposite. Therefore, for a gravity wave to grow stronger and go through into the upper stratosphere, the horizontal direction of the wave vector needs to be in opposite of the background wind velocity. Otherwise, if the Doppler shift is so severe that the phase of the wave becomes stationary in the wind frame, the wave becomes part of the flow and is absorbed. Such effect is called the directional filter. The background wind absorbs waves in one direction but allows them to pass in the opposite.

Following the above discussion, we know: first that MLS observed radiance variances are sensitive to the angle between the instrument LOS and the wave propagating direction; and second the wave propagation and survival are affected by the background wind. Thus we think that further analysis of the

MLS measurements with respect to the background wind should provide valuable insides of the gravity waves and their propagation properties.

In this study, we focus our radiance variance analysis on Northern Hemisphere wintertime (Dec-Feb) mid- to high latitudes (45N-80N). We use the global assimilated wind fields from the United Kingdom Meteorological Office (UKMO) as the background winds. For each MLS operation day, the winds data are interpolated from the equally-spaced latitude-longitude grids to the latitudes and longitudes along the MLS orbit track in order to computer the angle between the MLS LOS and the UKMO wind direction.

## 2. Dependence of radiance variances on stratospheric wind

Define the viewing angle  $\theta_w$  as the angle between the MLS LOS and the UKMO horizontal wind velocity ( $U$ ). Figure 1 (a) shows a three-year statistics (1994-1997) of the wintertime limb-tracking radiance variances sorted by viewing angle with  $10^\circ$  bins centered from  $0^\circ$  to  $180^\circ$ . Each angle bin contains more than 1000 limb-tracking measurements and the standard deviation of radiance variances is 10-15% about the mean. It can be seen clearly that at altitudes below 43km, the magnitude of the variances peaked at about  $90^\circ$  viewing angle. According to the limb-track variance response simulation [4], the variances near this  $90^\circ$  viewing angle implies that the related wave-front of the

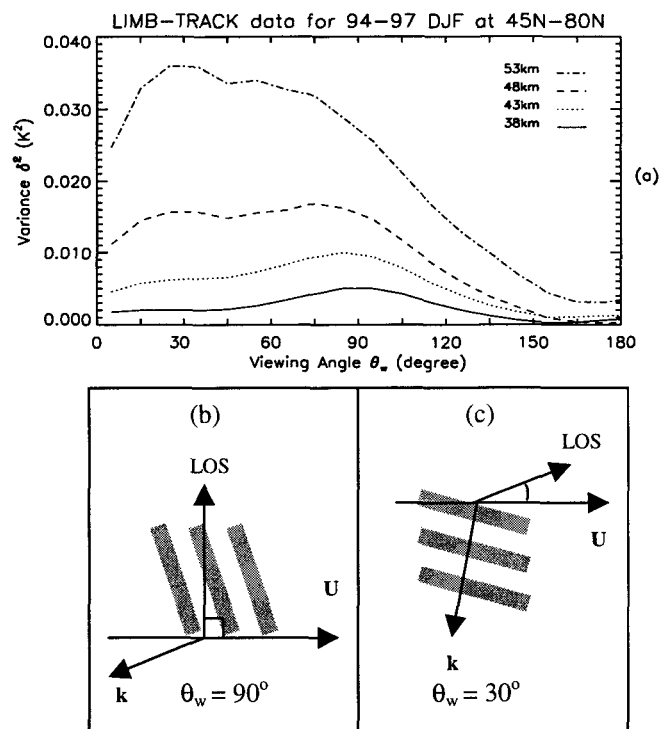


Figure 1

gravity waves is about  $150^\circ$  clock-wise from the wind direction [Figure 1 (b)], with the wave vector pointing towards nearly the opposite direction of the wind. It is known that during the winter season, the northern stratospheric jet-stream travels in a predominantly west-to-east direction with the actual path of the jet stream dips and rises at seemingly random places. This implies that the radiance variances observed near the  $90^\circ$  optimal angle might be associated with a mainly westward propagating wave. Another optimal angle in the Figure 1 (a) is around  $30^\circ$ . The magnitude of the radiance variances near this viewing angle apparently grows rapidly with altitude and dominates the variances at altitudes higher than about 48km. Based on the variance response simulation, the related wavefront observed near this  $30^\circ$  angle should be almost parallel to the wind direction, i.e. the wave vector is pointing away from the polar vortex [Figure (c)]. As we know, interactions of propagating gravity waves with background winds are important to interpret MLS radiance variances [5]. Because of the Doppler shifting effect, more vertical wave-number spectra move into the MLS filter ( $\geq 10$ km). Thus the MLS radiance variances increase when the background wind is intensified. The simplest form to relate the vertical wavelength to the Doppler shifting effect is

$$\lambda_z = (c - U \cos \theta_p) / N \quad (1)$$

where  $c$  is the wave horizontal phase speed,  $U$  is the horizontal background wind speed,  $\theta_p$  is the angle between the wind direction and the wave propagation direction and  $N$  is the buoyancy frequency. Apparently, when  $\theta_p$  nears  $180^\circ$  the wave propagates more closely to the opposite direction of the wind and therefore the Doppler shifting effect is stronger. By looking at Figure 1 (b) and (c), it is not difficult to expect that in the  $\theta_w = 90^\circ$  viewing angle region the observed variances should increase faster with wind speed than in the regions with  $\theta_w = 30^\circ$ .

Figure 2 (a) and (b) illustrate the limb-tracking radiance variances near the  $90^\circ$  and  $30^\circ$  optimal angles as sorted by horizontal wind speed at 5m/s bins. Both data was cut-off at high speed to ensure at least 400 measurements. The standard deviation of the variance is about 15%. It can be seen that for wind speeds less than about 60m/s, the observed radiance variances at both optimal angles increase with the wind speed, and as expected, the variances near the  $90^\circ$  optimal angle increase faster when wind speed becomes larger. However, when the wind speed exceeds about 60m/s, things become quite different near the two optimal angles. The radiance variances continue to grow near the  $30^\circ$  angle, but around the  $90^\circ$  angle, a zero-growth in radiance variances is reached. The Doppler shifting interpretation does not expect such growth saturation at higher wind speeds. It may be caused by wave breaking. In the earth atmosphere, internal gravity waves usually become statically unstable if dense air is lifted by the waves to such a degree that it overlies less dense air somewhere in the wave-field. Let  $\Theta = \tan^{-1}(k_z / k_x)$  be the angle at which the lines of constant phase tilt from the

vertical, where  $k_x$  and  $k_z$  be the horizontal and vertical wavenumbers, respectively. A recent study by Sutherland [6]

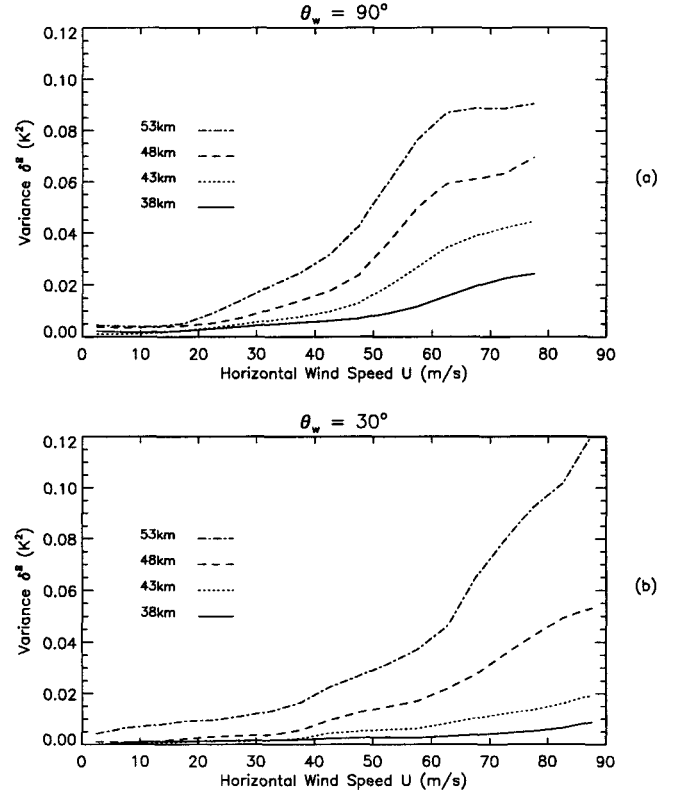


Figure 2

showed that the criteria for an internal gravity wave to break is that the ratio ( $A_c$ ) of the maximum vertical displacement of the wave to its horizontal wavelength satisfies:

$$A_c = \cot^{-1}(1 + \cos^2 \Theta) / 2\pi \quad (2)$$

Note that  $A_c \rightarrow \infty$  as  $\Theta \rightarrow 0$ . In other words, the breaking condition is easier to be made when  $\Theta$  is larger. Therefore, it may be speculated that the waves in the  $90^\circ$  optimal angle region propagate in more upward direction than the waves in the  $30^\circ$  optimal angle region (Figure 3). The waves associated with the  $90^\circ$  viewing angle are easier to meet the breaking criteria because

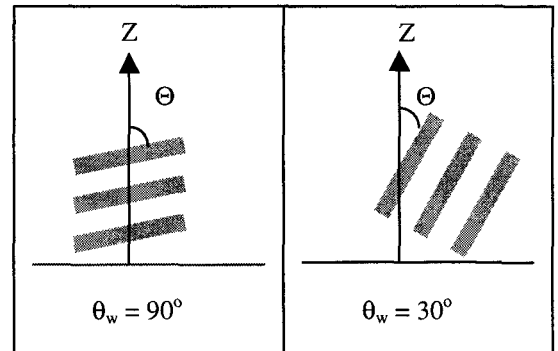
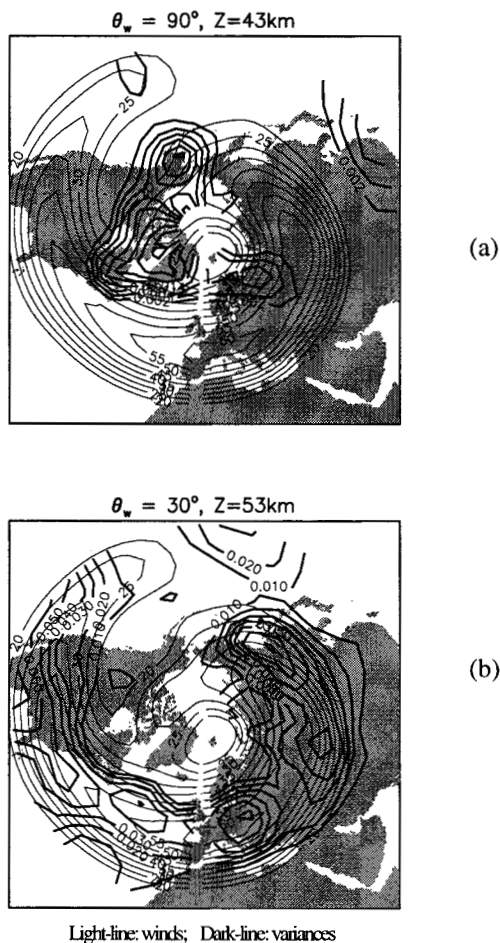


Figure 3

of larger  $\Theta$  and therefore smaller  $A_c$ .

Regions associated with the radiance variances of the  $90^\circ$  and  $30^\circ$  optimal angles are mapped on Figure 4 (a) and (b), respectively. Clearly, the variances of the  $90^\circ$  optimal angle seem to be produced by the gravity waves located near the center of the vortex over Alaska, Canadian High Arctic and Greenland. The variances of the  $30^\circ$  angle, on the other hand, are located close to the edge of the polar vortex above land surfaces in the Northern Hemisphere.



**Figure 4**

Furthermore, as shown in Figure 5, when we sort the upper-stratospheric air temperature according to the horizontal wind speeds, we found that inside the polar vortex ( $\theta_w=90^\circ$ ) the air temperature increased up-to about  $20^\circ\text{C}$  as the corresponding gravity waves broke down. The temperatures near edge of the jet stream ( $\theta_w=30^\circ$ ), however, was found to have little variation with wind speed.

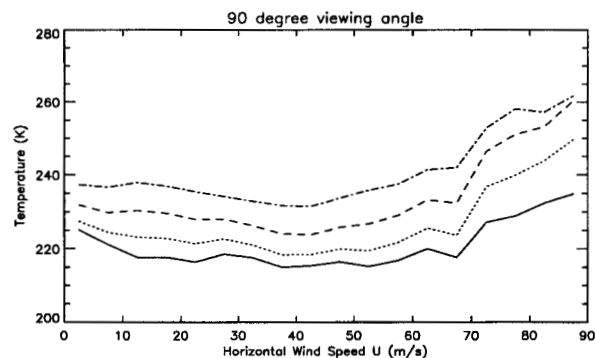
### 3. Discussion

The nature of atmospheric waves associated with the polar vortex is a complex problem that until today remains largely

unknown. The filaments of vortex air that are entrained into the subtropical zone may be associated with the atmospheric wave activities that MLS observed at the edge of the jet stream. Our recent analysis with limb-track variances of different horizontal scales indicates that the wave activities near the edge of the jet stream have dominant horizontal scales ranging from 400km to 800km. On the other hand, the MLS variances inside the polar vortex appear to be generated by sources of horizontal scales smaller than about 200km, which is the typical scale of internal gravity waves. We expect that much of these internal gravity wave sources might be generated by the airflow over the rough terrain such as the Alaska Range and Mackenzie Mountains in Canada Northwest Territories. These waves grow, propagate upward into the stratosphere, and then breakdown releasing heat to the local environment. Our future investigation will combine UARS MLS, balloon radiosonde and GPS occultation data to confirm the above understanding.

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**Figure 5**

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